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EVERETT 49, MASSACHUSETTS

Quarterly Report No. 1,
DEVELOPMENT AND FEASIBILITY PROOF OF THE DRY
TAPE BATTERY CONCEPT

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ABSTRACT

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Feasibility of the "Dry Tape Battery" concept has been demonstrated on a laboratory test device with the $\text{Ag}_2\text{O}_2/\text{KOH}/\text{Zn}$ system. Tapes coated with Ag_2O_2 have been discharged successfully both alone (with separate electrolyte feed), and in a "dual-tape" system. The "dual-tape" system employs a separate prewet tape to feed KOH electrolyte and serve as separator. A stationary zinc block served as current collector and anode while silver plate or screen was used as a cathode current collector. Current densities as high as 1.6 amp/in.² have been maintained with a current efficiency of 75% at a tape speed of one inch per minute. Output was 1.22 amps at 1.24 volts with the following energy densities:

Watt-hr/lb

108	dry tape with Ag_2O_2 coating and binder
68	above +110% of thcor. zinc and separator
48	above + theor. amount 30% KOH
25	above + actual amount 30% KOH

Design and testing of a prototype and final design of an activation unit for the demonstration of the dual-tape system have been completed as have component design and testing. The prototype outputs were essentially the same as those obtained on the laboratory test device.

Four activation units are being assembled for demonstration.

AUTHOR

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constructed before the formal start of this project. This device in its present form and associated instrumentation are shown in Figure 1. The current collectors were modified to permit control of contact pressure. The feeding system was modified to allow lower electrolyte feed rates. Also, the system was modified to allow "dual-tape" operation, that is, to feed electrolyte on an uncoated tape that joins the coated tape just prior to the current collectors.

The tape is driven by a variable speed dc motor coupled to a reducing gear box and a torque measuring device. Electrolyte is fed from a micrometer syringe (6) powered by a Zero-Max variable speed drive (7). A wicking pad (5) under the tape distributes electrolyte to the tape as it moves to the current collectors. A Teflon[®] felt wicking pad, which was somewhat difficult to wet, has been replaced with one of non-woven Nylon[®].

The test unit is shown set up for operation with a "dual-tape" system in Figures 1 and 2. The dry Ag_2O_2 coated tape (1) is pulled over a platform and then passed between stainless steel rollers (17), where it is pressed against the previously wetted electrolyte feed/separator tape (13). The separator tape is wetted as it passes over the electrolyte wicking pad (5). The wetted tape (15) is drawn with the separator between the current collectors (2), the lower one of which is a zinc block. The upper current collector, a silver plate mounted on Plexiglas[®], is positioned by the guide (14) and screws (18). The discharged tape (16) is drawn up on the take-up spindle (3), which is driven by torque rods (12).

1. Cathode Collector

The cathode collector was originally a flat silver strip under which the Ag_2O_2 -coated tape passed. It was found that performance of tapes with rough coatings could be improved by use of a flexible grid of expanded silver as the current collector. With somewhat smoother coatings, no noticeable improvement was found with expanded silver. The area of the cathode collector (and the coated tape width) has been reduced to 0.765 in.² (7/8 in. x 7/8 in.) to provide more reliable operation with the "dual-tape" system now being used. The collector weighs approximately one ounce, and contact pressure can be varied by the addition of one-ounce weights.

As an alternative to the flat sliding collector described above, a roll collector was built and tested briefly. The purpose of this was to reduce the force required to pull the tape. The roll collector consists of four 1/8-in. diameter gold-plated rolls set in a holder. Preliminary tests indicated that the higher current densities encountered at the roll contact areas were tolerable.

I. INTRODUCTION

A. OBJECTIVE

The major objective of this work is to demonstrate the feasibility of the "dry tape" concept by constructing a breadboard device to use experimentally coated tapes based on the $\text{Ag}_2\text{O}_2/\text{Zn}$ couple. In addition, the operating parameters of this experimental system are to be determined so that reasonable extrapolations of system capability for larger systems and other electrochemical couples can be made.

B. BACKGROUND INFORMATION

The "dry tape" concept in its ultimate form involves the use of a thin separator tape on which are coated the active components of an electrochemical system (oxidant, reductant, electrolyte, electrode, etc.). This tape can then be fed continuously or intermittently to a set of current collectors that would activate the system, allowing the electrochemical reactions to take place. The major advantages visualized for such a system are, first, reduction of concentration and activation polarization through continuous feed of reactant and removal of products and the continuous feed of fresh electrode surface. Second, such a system would allow the use of known high energy couples in high rate applications, whereas in conventional battery systems these same couples would be limited to low rate applications because of mass transport limitations. A third advantage of the dry tape concept is that with reserve-type materials activation of components would occur only as they are needed, permitting unlimited storage of the unactivated portion of the tape.

The complete development of such a system would require a total effort that is not justifiable until the feasibility of the basic concept is demonstrated. For this reason, our major effort has been to demonstrate the feasibility of the concept in a very elementary form. Work on electrolyte encapsulation, catalysis, etc., is not being considered in this initial program. For demonstration purposes, the $\text{Ag}_2\text{O}_2/\text{Zn}$ couple is being used for comparison with other high rate battery systems. It is not the purpose of this program necessarily to optimize this particular couple but rather to demonstrate its feasibility by determining the operating parameters so that sound extrapolations to future system capability can be made.

II. PHASE 1A. MECHANICAL

A. LABORATORY TAPE EVALUATION DEVICE

A laboratory test device for evaluation of experimental tapes was

KEY FOR FIGURES 1 AND 2

- 1 Dry tape, Ag_2O_2 coated
- 2 Current collectors
- 3 Tape take-up
- 4 Take-up drive and motor
- 5 Electrolyte wicking pad
- 6 Electrolyte pump (micrometer syringe)
- 7 Zero-Max pump drive, variable speed
- 8 Tape take-up speed control
- 9 Load box, 1 ohm steps
- 10 Dual pen recorder
- 11 Current shunt
- 12 Tape drive and torque meter
- 13 Separator tape, wet
- 14 Tape guide-cathode current collector guide
- 15 Wetted tape
- 16 Discharged tape
- 17 Contact rolls
- 18 Cathode current collector positioning screws

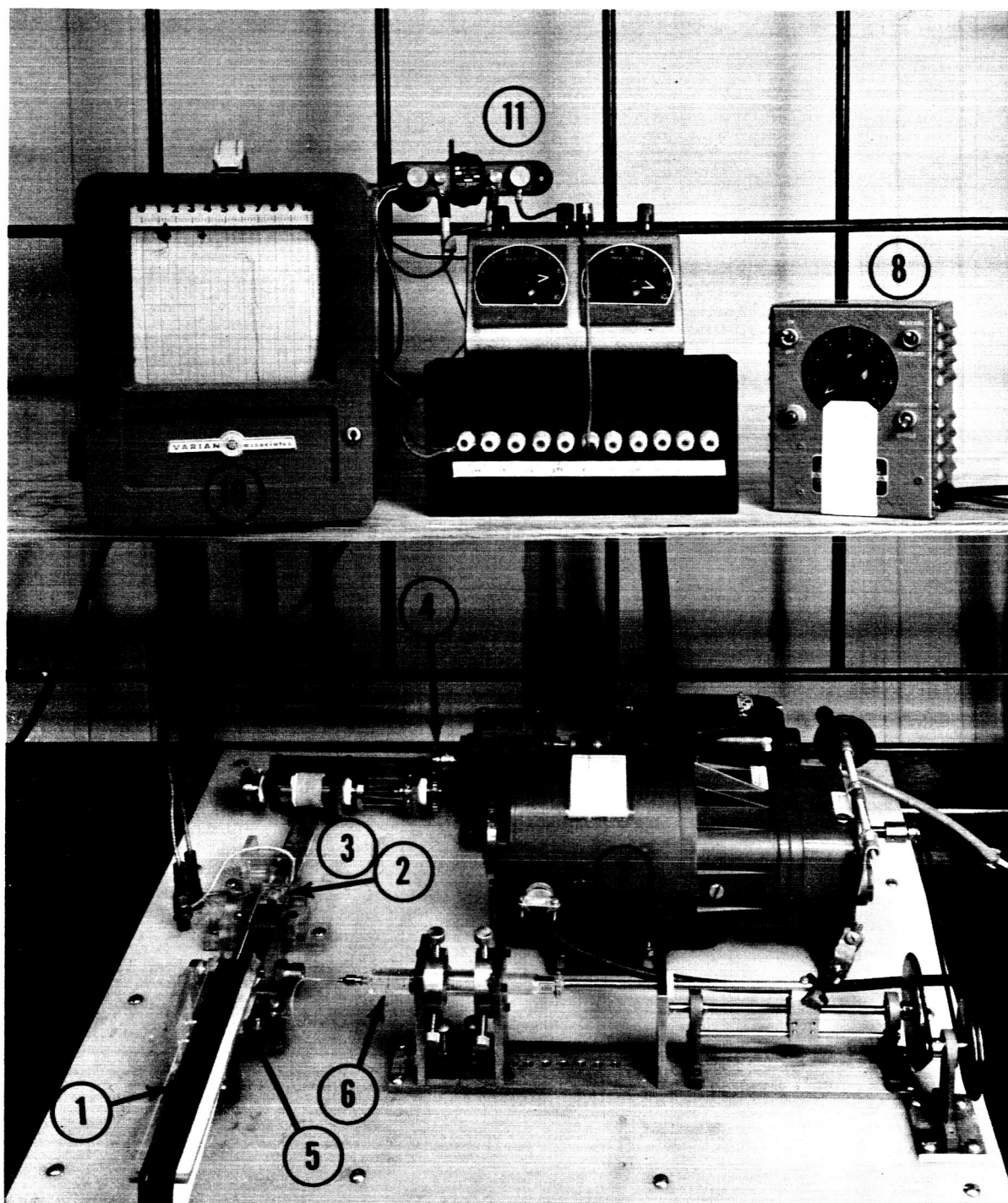


Figure 1. Laboratory Tape Dynamic Test Device

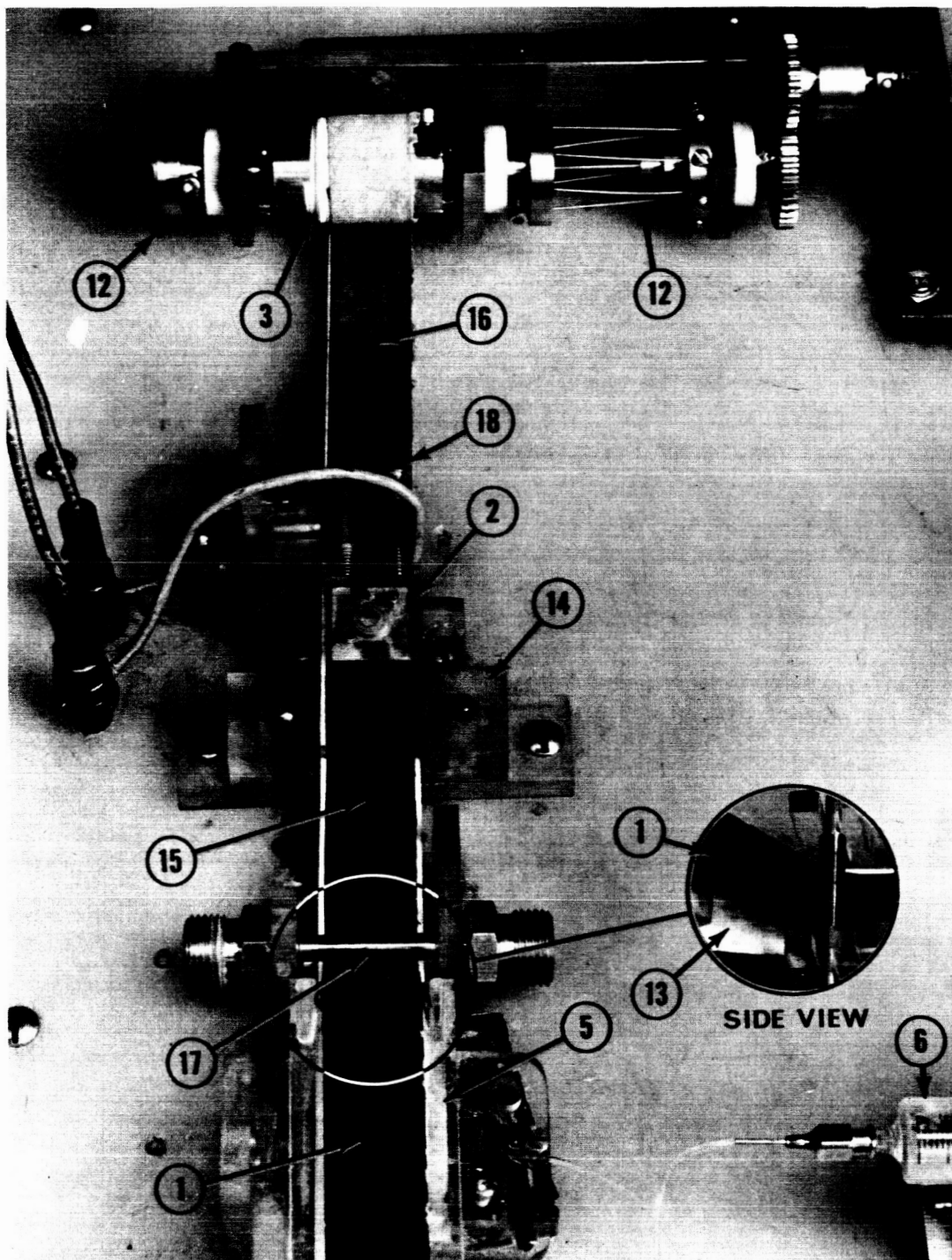


Figure 2. Tape Section of Dynamic Test Device - Dual Tape Operation

2. Anode Collector

For this feasibility study, the zinc anode material is not coated on the opposite face of the tape but rather will be present as a block over which the activated tape is drawn. The zinc block also serves as the anode collector. This arrangement appears satisfactory except during intermittent operation where fouling and pitting of the zinc surface has been found to occur. This is discussed further under Test Results.

Expanded zinc screen was also tried as the anode collector but no improvement in performance was noted. The screen itself was consumed in a relatively short period of operation. To provide additional surface area for higher anode current densities, sintered zinc powder and pellet rolls have been fabricated and will be tested.

3. Discharge Circuitry

The electrical load consists of a resistance box with ten 1-ohm (25 w) resistors connected in series and tapped at 1-ohm steps. These resistors and the circuit resistance were measured with an Electro Scientific Industries Universal Impedance Bridge. The 1-ohm resistors (connected) were found to be within 2% of that value, and the circuit resistance was approximately 0.075 ohm (excluding electrodes) of which 0.05 ohm could be attributed to the current shunt. Some of the more recent tapes tested have maintained voltage output through the 1-ohm load so that a variable resistance down to 0.5 ohm or less will be added. Electrical output is measured with a Varian G-22 Dual Channel Recorder providing a continuous record of current and voltage. Full-scale voltage was 2 volts, and 1- and 2-amp (full scale) shunts were generally used. Accuracy was 2% of full scale or better. A chart speed of 2 in./min was used to give a convenient and accurate comparison with tape speed (usually 1 in./min.).

B. DESIGN AND CONSTRUCTION OF FOUR BREADBOARD DEMONSTRATION DEVICES

To demonstrate the feasibility of the tape concept it is necessary to construct prototype hardware in which coated tapes can be activated and discharged in a continuous manner.

Because of time limitations, certain design considerations were initially agreed upon:

1. The unit should be completely self-contained (drive tape, electrolyte, etc).
2. A spring-wound mechanism (off the shelf) would be used for tape transport.

3. A zinc block, over which the Ag_2O_2 tape is passed, would serve as the anode rather than using a zinc coating on the tape.
4. Commercially available Ag_2O_2 would be used directly as the cathodic material rather than in situ electrolytic formation.
5. The configuration of the components in the prototype should occupy as small a volume and be as light as possible consistent with using "off the shelf" parts wherever possible. Weight and volume savings would be extrapolated from the prototype by suitable component design.
6. The prototype should be capable of continuous operation for a period of at least 10 minutes, limited only by the length of tape, even though the mechanical system capacity would be much higher.
7. Although an ultimate goal would be to use electrolyte encapsulation, for demonstration purposes this was not necessary.

As the work progressed, a further constraint was put on the system. We felt that for the short operating periods required for demonstration, a weight saving and more reliable operation could be obtained by using a dual-tape system in which the electrolyte would be fed on a second tape saturated with aqueous KOH. This greatly simplified the electrolyte pumping system.

1. Component Design and Testing

To check out possible mechanical designs for the breadboard demonstration devices, it was necessary to construct a test stand in which the mechanical features of all proposed components could be determined individually and in conjunction with one another. This test stand is shown in Figures 3 and 4. Based on their performance in this test stand, the design of the various components was frozen for incorporation into the final devices.

It is interesting to note that the electrical output of a tape tested in this rig was identical with that obtained in the tape evaluation device.

2. Breadboard Demonstration Device, Design and Fabrication

a. General Description of the Prototype Model

During this reporting period, the components for the breadboard dry tape battery prototype were fabricated and tested individually and

List of Components for Figs. 3 and 4

1. Spring-wound drive (Keystone A-7-3) with disengaged centrifugal governor
2. Attached escapement mechanism
3. Tape transfer drive
4. Current collectors
5. Ag_2O_2 -coated tape
6. Electrolyte wetted tape

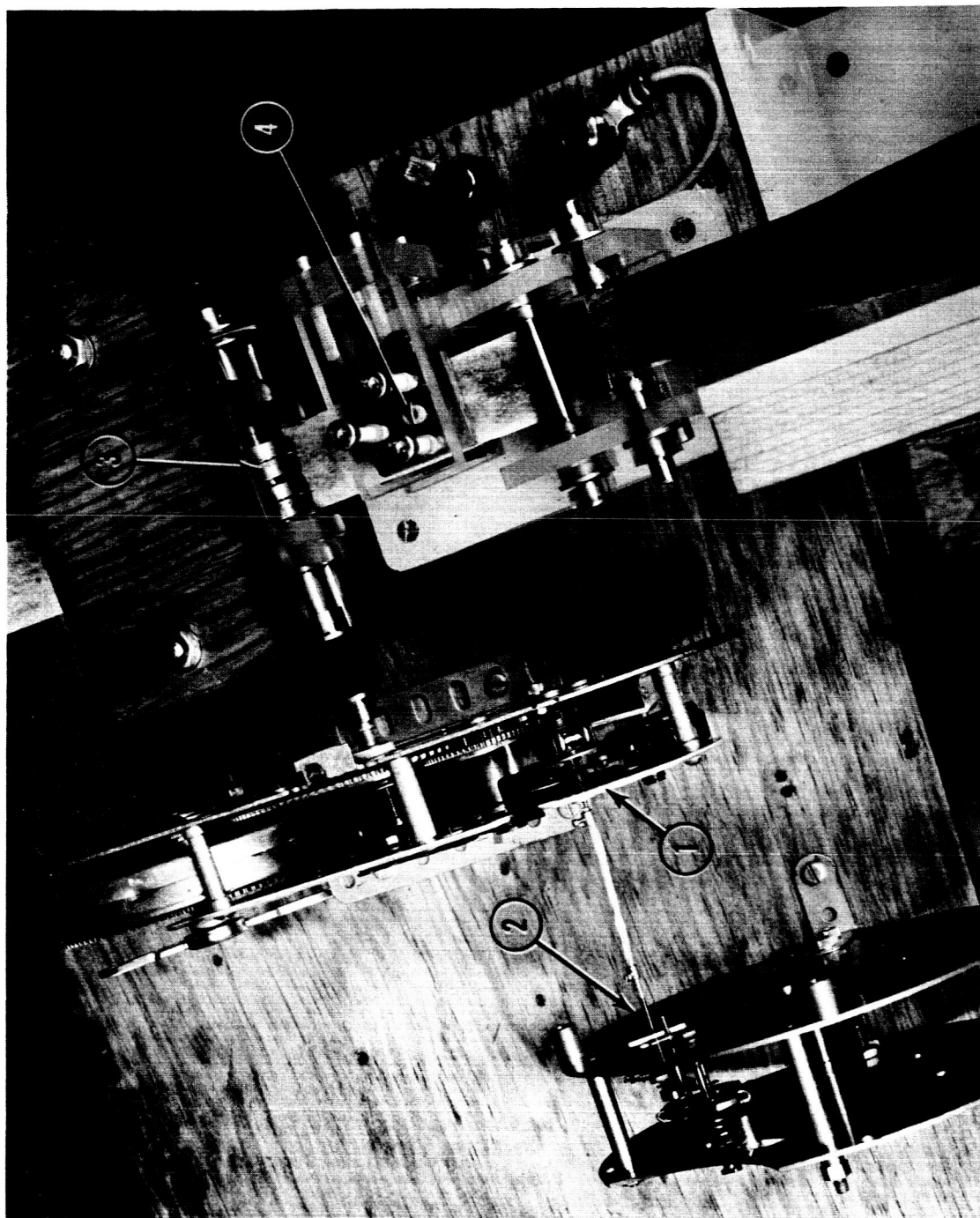


Figure 3. Component Test Stand -- Top View

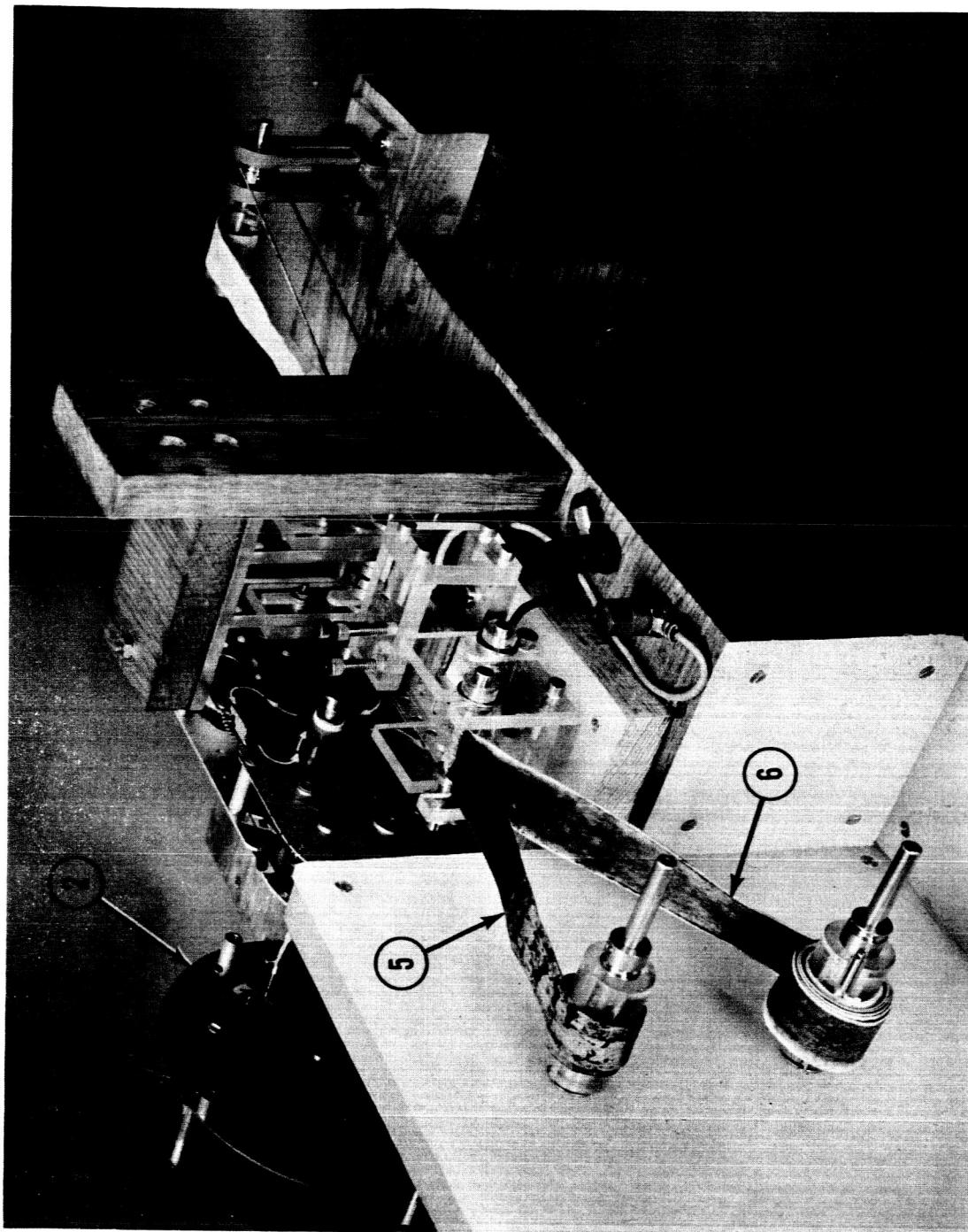


Figure 4. Component Test Stand - Oblique View

collectively. The construction of a prototype model is now well underway.

Basically, the breadboard units will consist of two major sections. The first contains a spring-wound drive permanently mounted in a carrying case. Also mounted in this case will be a variable load resistor and meters for demonstration. Four such cases are to be built.

The second section, which we call the "tape deck", will be a self-contained unit comprised of tape-feed spools, take-up spools, etc. Each tape deck will contain sufficient tape for approximately 10 minutes of continuous operation and can be "plugged into" any of the drive units. It is planned to supply between 10 and 20 such tape decks for demonstration at the conclusion of this contract.

A pictorial view of this proposed model is shown in Figure 5. Figure 6 is a plan view of the proposed tape deck in which is mounted the tape feed spools, the take-up spools, current collectors, and tape drive sprockets.

Referring to Figures 5 and 6, the tape containers within the tape deck are preloaded with the silver peroxide-coated tape and electrolyte-saturated tape. Non-permeable leaders attached to these tapes are threaded through the operating path as shown by the arrows in Figure 6. This preloading is done during the actual fabrication of the tape deck, not just prior to use of it. To start the unit, a tape deck is plugged into the carrying case over the spring-wound motor section. The process of "snapping in" automatically connects the tape transfer roller shaft and the take-up spool shaft to the spring motor. The couplings are so designed that the process is self-aligning.

Before actually starting the cell, the seal from the electrolyte tape container must be removed and the tape advanced until the active coating is within the current collectors. Pushing the start lever on the spring-wound motor will then put the cell into operation.

Details of the individual components of both the drive unit and the tape deck are discussed in the following section.

b. Detailed Component Description

(1) Spring-Wound Motor

It was decided at the start of this contract, that for the sake of simplicity, a spring-wound motor would be used to drive the tape system. Previous experiments showed that the drive should be able to provide a shaft output of 10-12 in.-oz of torque at 0.568 rpm. A further requirement was that the spring-wound motor should run at least 20 minutes at constant speed after a complete winding.

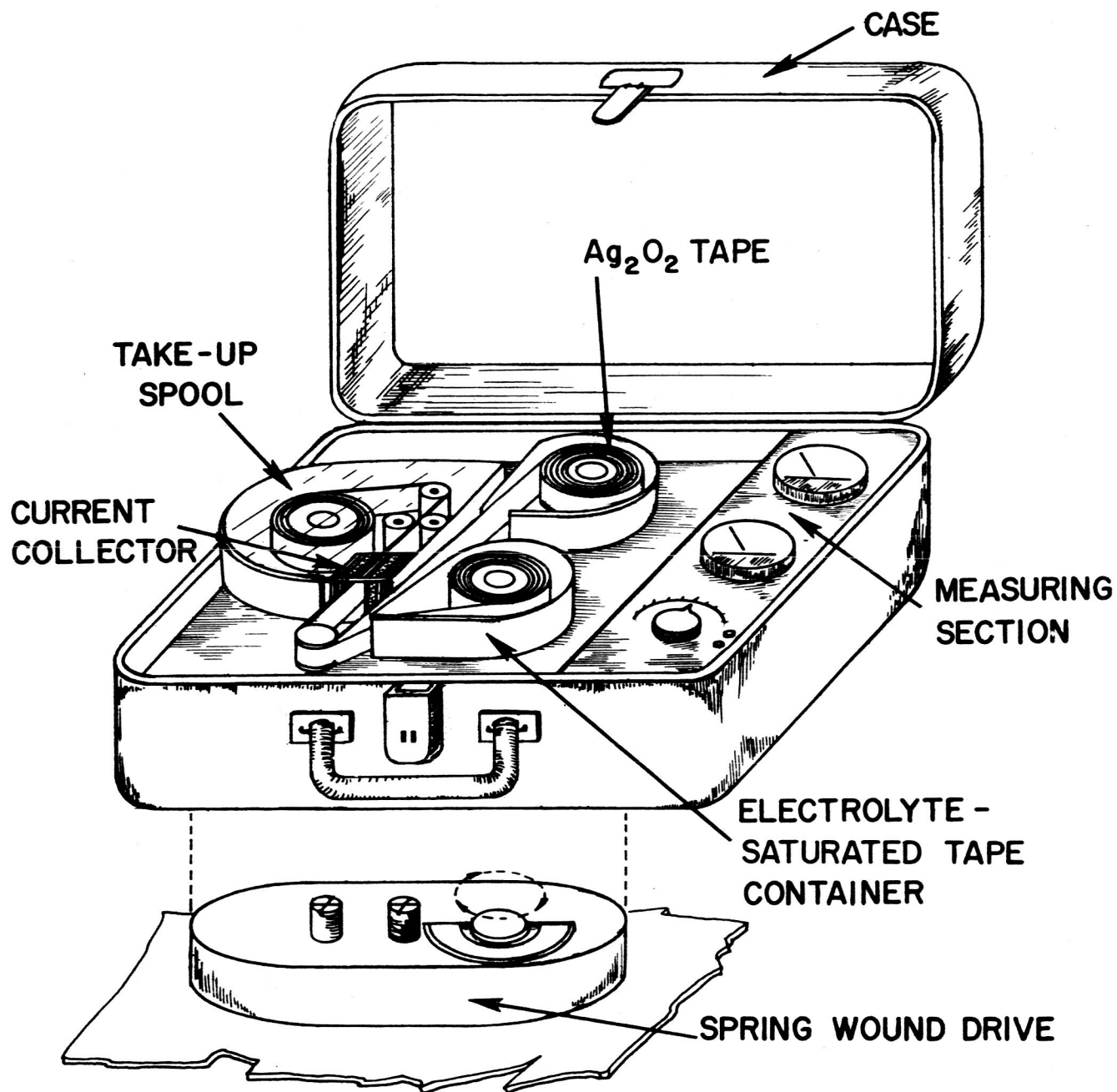


Figure 5. Prototype Demonstration Model of Dry-Tape Battery

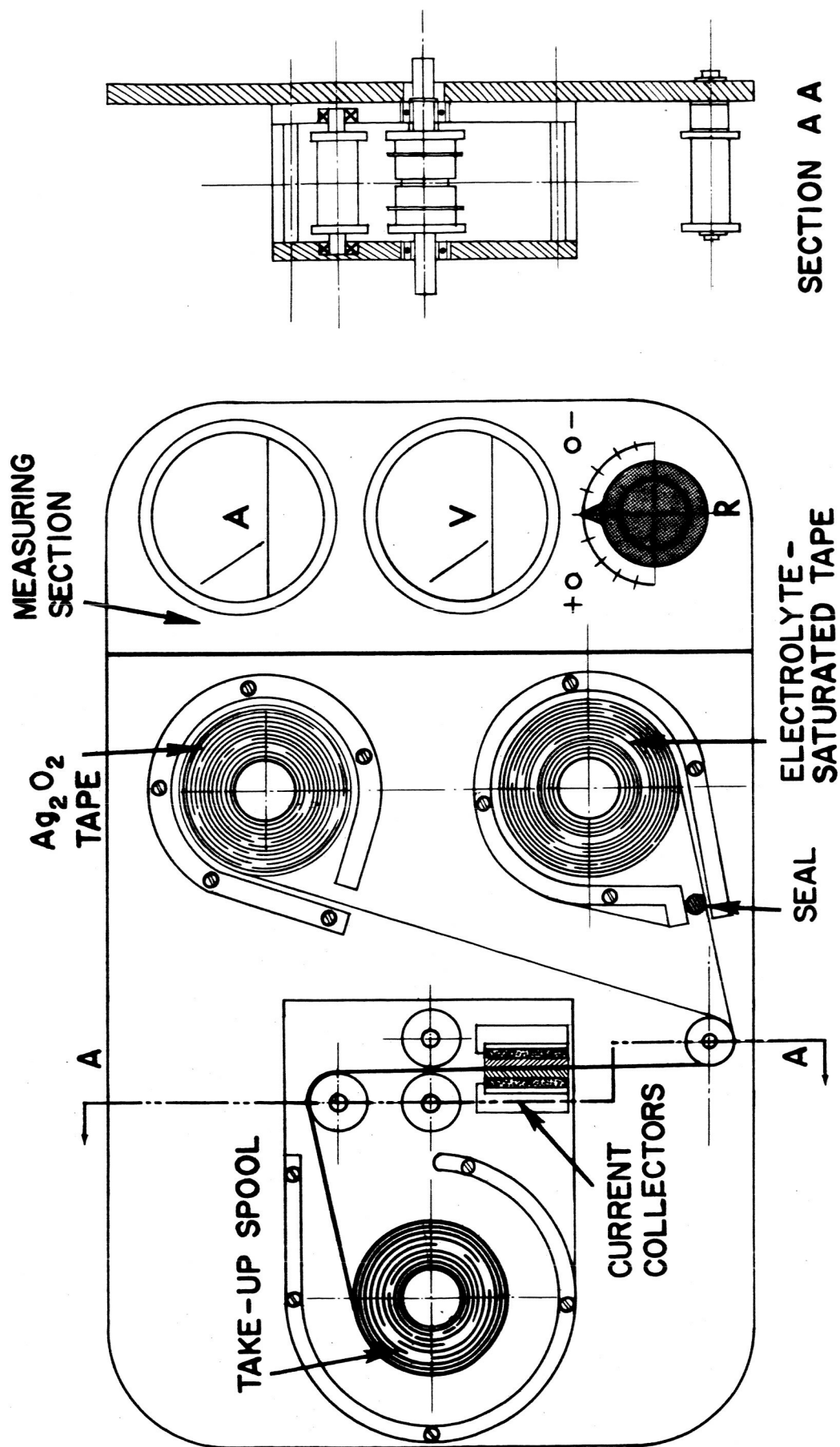


Figure 6. Tape Deck Assembly of Prototype Demonstration Battery

Because of the tight time schedule for this work, it was necessary wherever possible to select off-the-shelf components rather than design them individually. For this reason, it was necessary to take a weight penalty in obtaining a commercially available spring-wound motor that would do the job. It was found that the drive mechanism of a Keystone movie camera, 16 mm (No. A-7-3) with the following specifications would be satisfactory with modifications:

Output shaft speed:	60 rpm minimum
Output shaft torque:	20 in.-lb when fully wound
Max. running time:	65 sec
Take-up spool shaft speed:	60 rpm minimum
Take-up spool shaft torque:	approx. 0.5 in.-lb
Weight:	2.3 lb

It was found that the original speed control of the camera drive was insufficient to reduce the output shaft speed to 0.568 rpm. For this reason an escapement mechanism of a chart drive clock was connected to the camera drive in place of a centrifugal regulator originally supplied. The general layout of this modified spring-wound drive is shown in Figure 7. The heavy black outline designates the transplanted escapement mechanism incorporated into the original Keystone drive unit.

Although the drive was originally modified in our own laboratories, four units to be incorporated in the final hardware are being fabricated under purchase order by the Keystone Camera Company.

(2) Tape Transfer Drive

The threaded tape within the tape deck is pulled along its operating path by means of a pair of sharp sprocket-equipped rollers shown in Figures 8 and 9. The gap between these rollers is set at 0.025 in., larger than the combined thickness of the tape and separator in the dual-tape system. Thus, the tape is transferred by the progressive motion of the penetrating sprockets. The optimum shape and dimensions of sprockets that would operate equally well on all combinations and thickness of tapes and separators have not yet been developed, but good transfer characteristics are obtained with triangular-shaped 5-mil thick stainless steel spikes.

The shaft of the drive roller is supplied with a cross pin that, after insertion into the spring-wound drive unit, automatically engages the flexible coupling of this drive. The rollers rotate at a speed of 0.568 rpm and drive the tape at a linear rate of approximately 1 inch per minute.

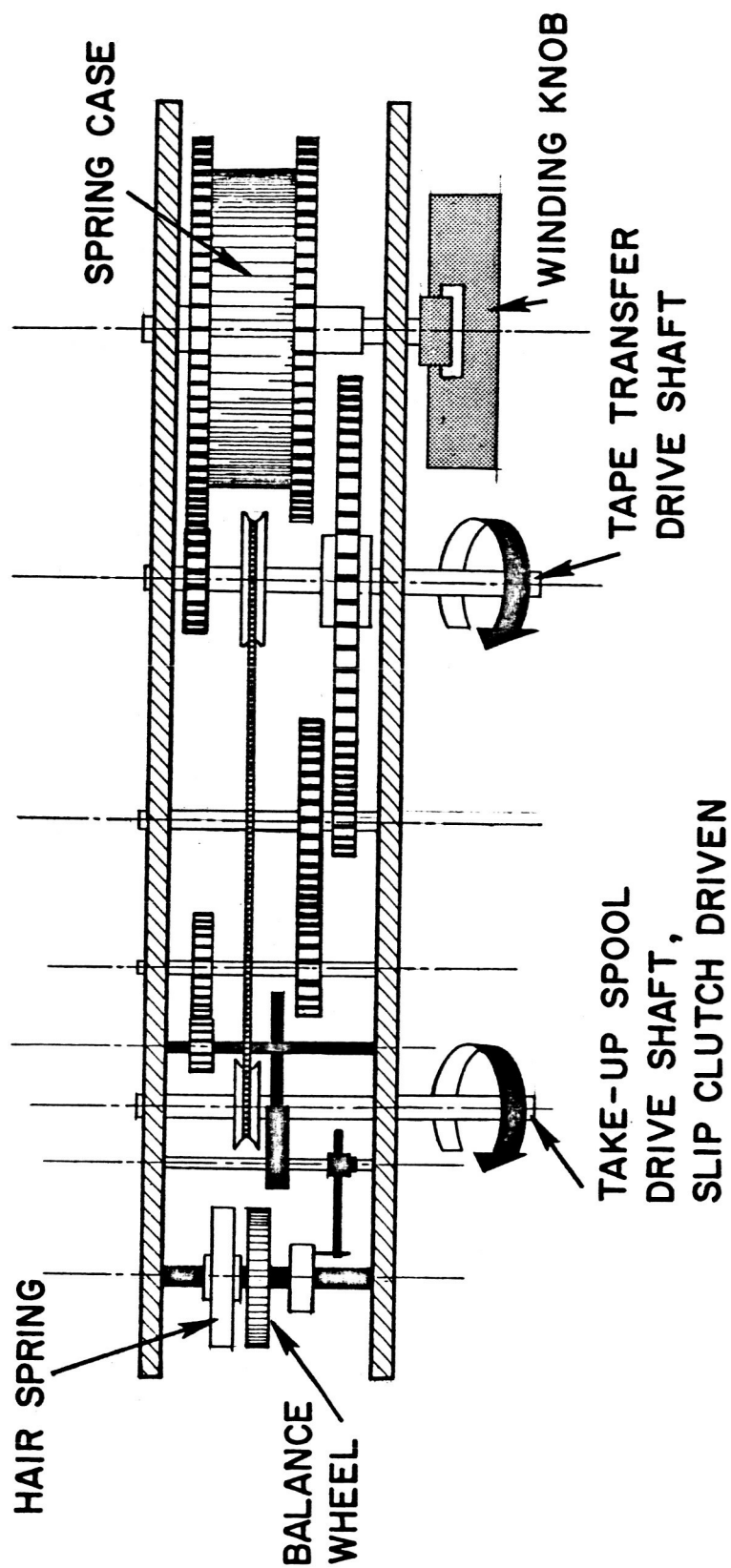


Figure 7. Spring-wound Drive Unit - Top View

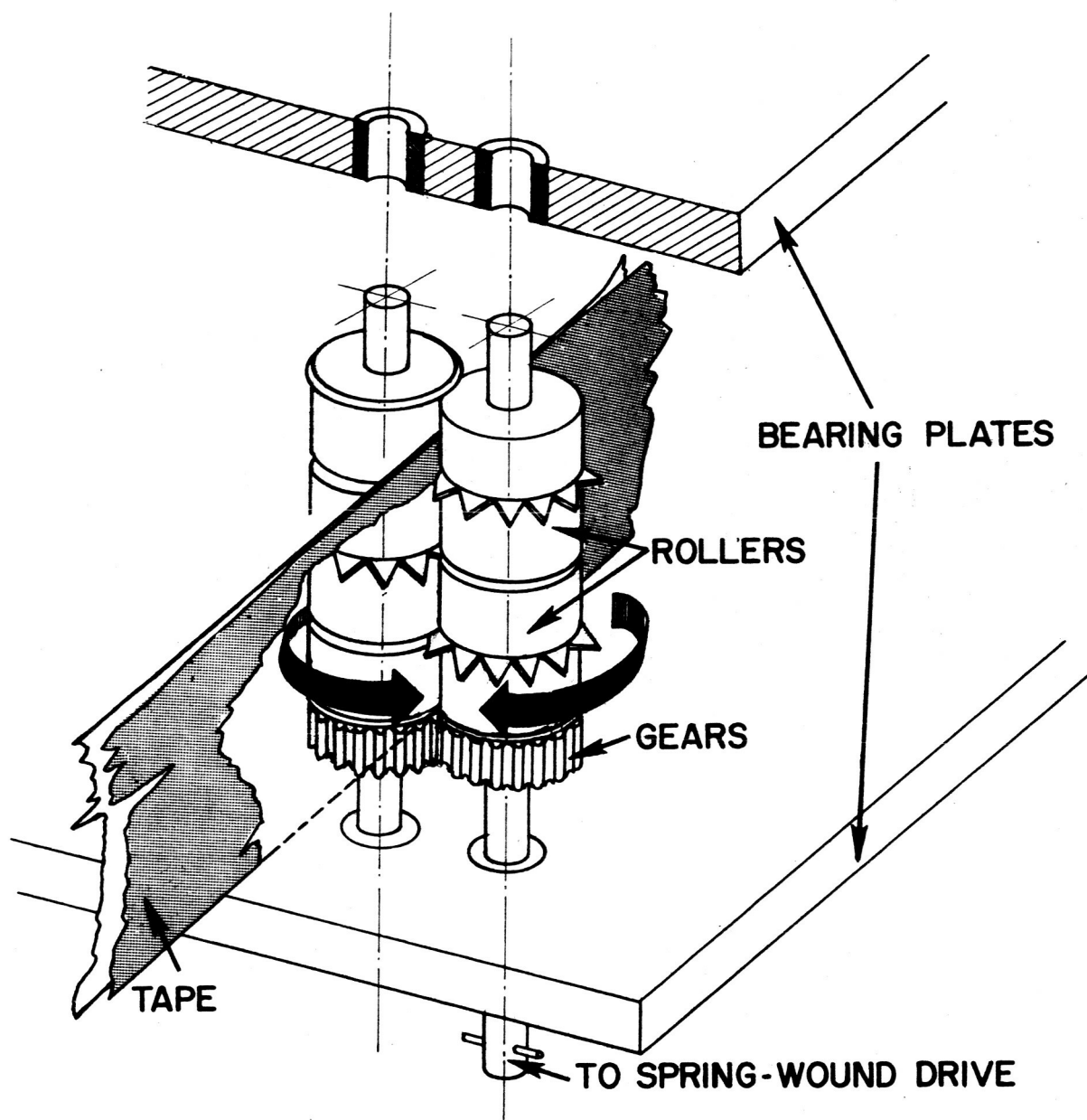


Figure 8. Tape Transfer Drive Showing Tape Position

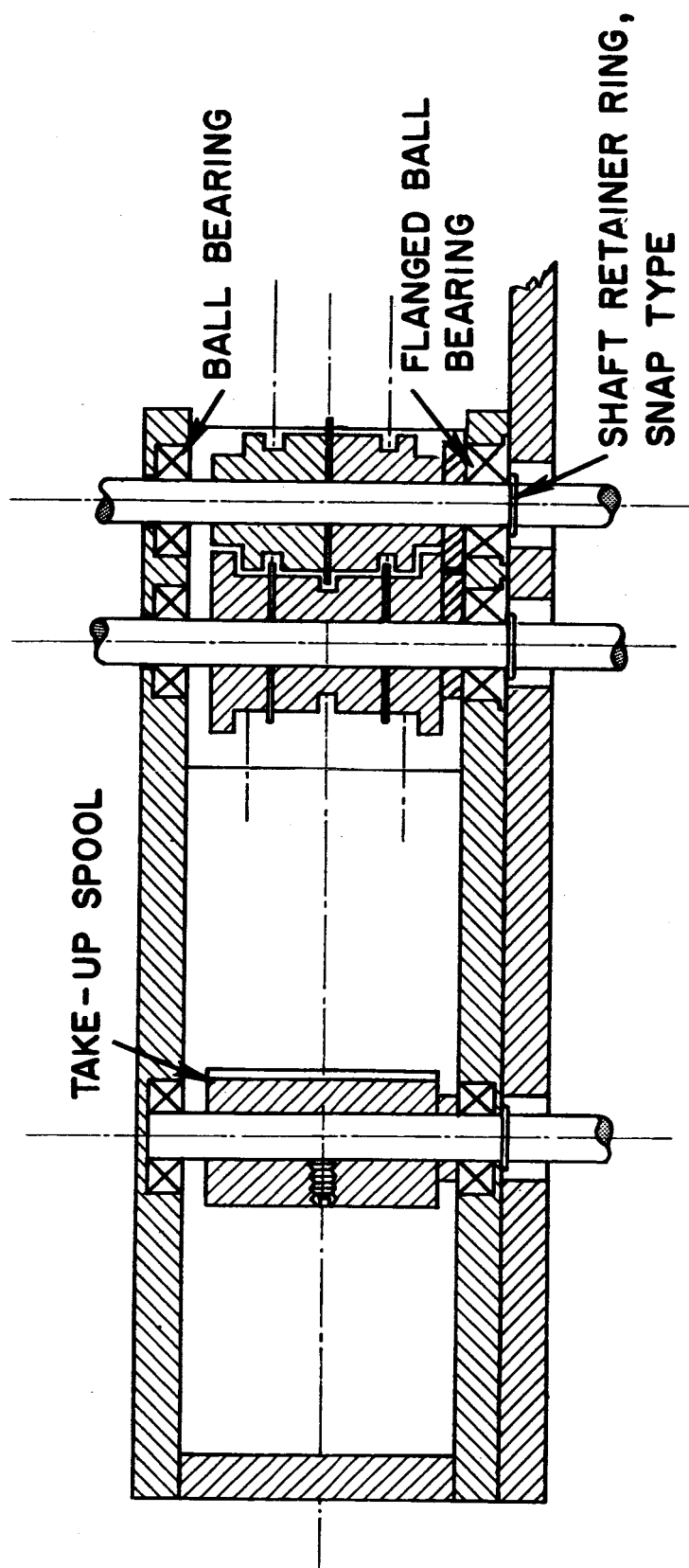


Figure 9. Cross Sectional View of Tape Drive Unit

(3) Current Collectors

The current collectors, shown in Figure 10, were designed to fulfill the following requirements:

- (1) Even contact pressure over the moving tape and the stationary anode.
- (2) Knee-action to follow small unevennesses of the tape.
- (3) Simple assembly and disassembly.

One of the two current collectors is made of fine silver and serves as the cathode collector. The other consists of a zinc block and serves as both current collector and anode. Each of the elements is of sandwich structure and consists of the current collector metal bonded to 1/4 in. thick urethane sponge, which in turn is bonded to a Plexiglass® backing plate. The total width (D) of the electrode casing was selected to give approximately 6 oz/in.² of pressure between the current collectors.

(4) Container for Electrolyte-Wetted Tape

Since in the dual-tape system an electrolyte-saturated tape is stored on a separate spool, it is necessary in some manner to seal this container to prevent loss of electrolyte to the atmosphere until the tape is ready for use. Although there are many methods of sealing this container, one of the simplest and most effective appeared to be a small piece of rubber rod compressed into the lip opening of the container, which effectively gaskets the non-permeable section of the leader tape. This configuration is shown in Figure 11.

A mock-up container was constructed using this sealing method and checked for leaks using internal air pressure equivalent to the partial pressure of water vapor above 30% KOH at 120°F. No visible leakage was observed.

This rubber seal, as previously described, is removed by a manual operation just prior to the use of the tape deck.

III. PHASE IB. CHEMICAL

A. ELECTROCHEMICAL SYSTEM

The Ag₂O₂-Zn system has been used in this work to allow comparison with a known battery system capable of high discharge rates. The electrochemical equivalents for this system are listed below. The

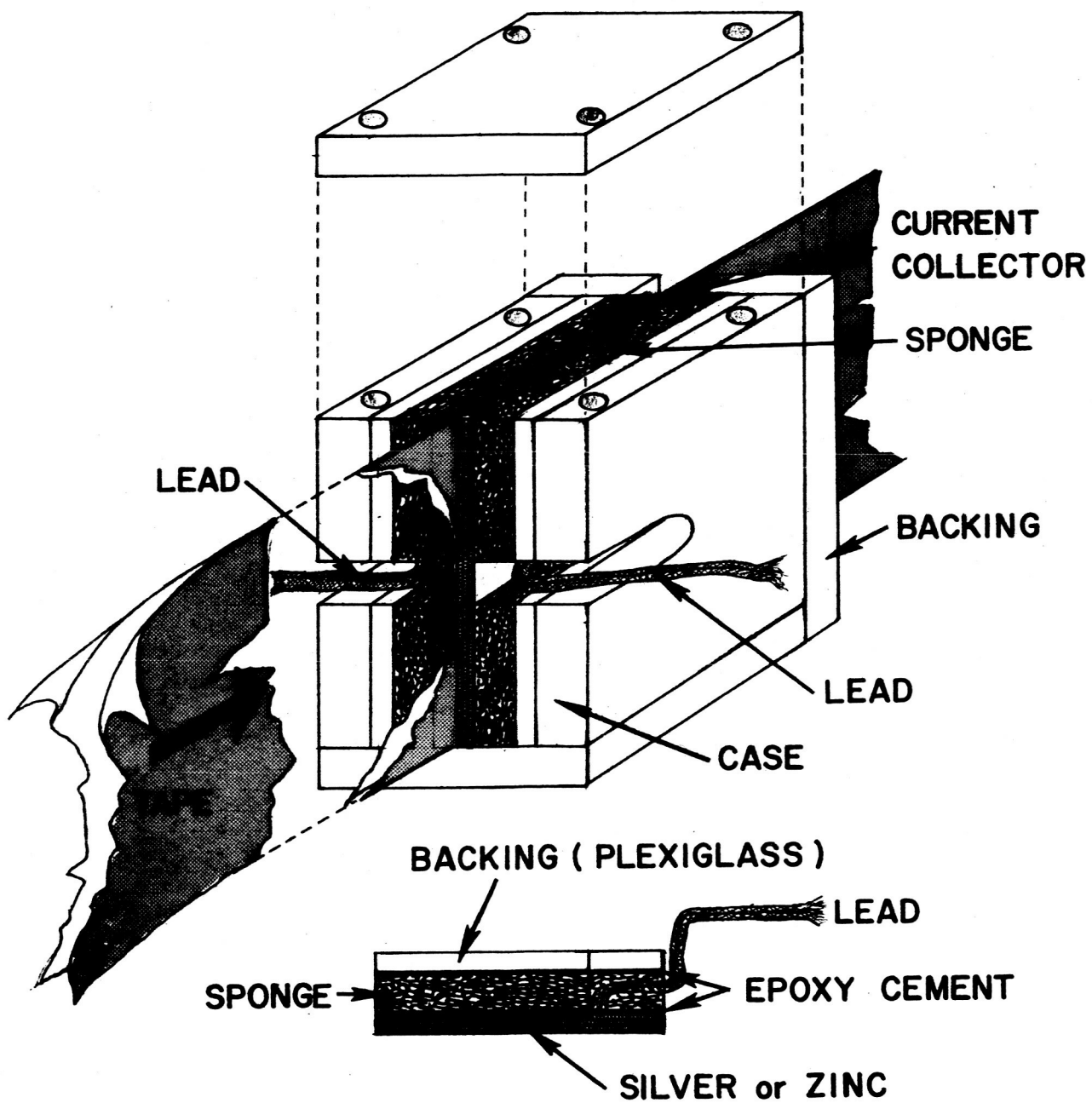


Figure 10. Current Collector Assembly

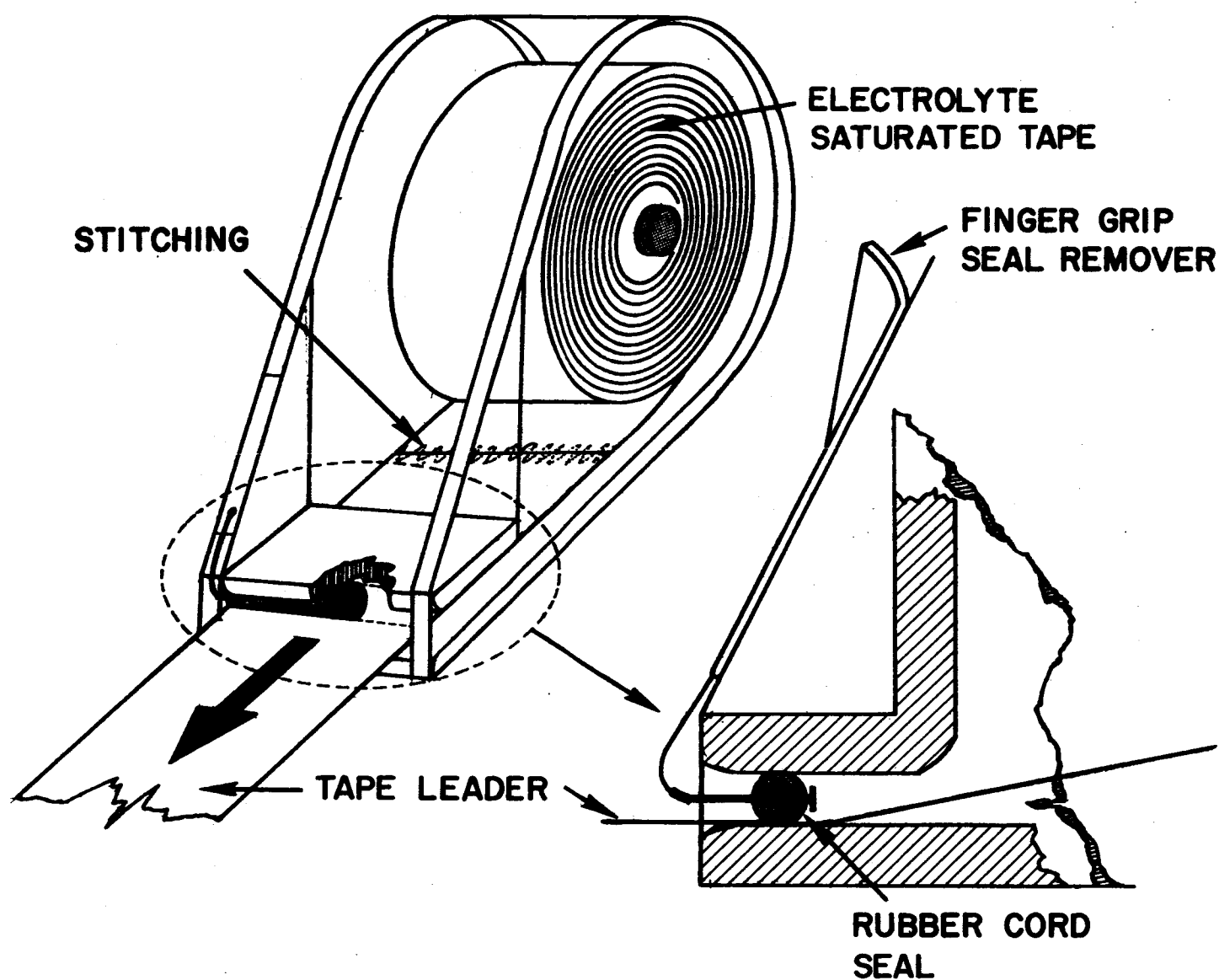


Figure 11. Electrolyte - Saturated Tape and Container

quantity of electrolyte required depends upon which reaction predominates: 1a, 1b, or 1c.

	Theoretical Energy Density, Watt-hr per lb reactants	
	As Written	Using 30% KOH
(1a) $\text{Ag}_2\text{O}_2 + 2\text{Zn} + 2\text{H}_2\text{O} = 2\text{Zn}(\text{OH})_2 + 2\text{Ag}$	176	169
(1b) $\text{Ag}_2\text{O}_2 + 2\text{Zn} + 2\text{KOH} = 2\text{KHZnO}_2 + 2\text{Ag}$	149	97
(1c) $\text{Ag}_2\text{O}_2 + 2\text{Zn} + 4\text{KOH} = 2\text{K}_2\text{ZnO}_2 + 2\text{H}_2\text{O} + 2\text{Ag}$	121	65

The theoretical energy densities listed with the reactions assumes complete discharge at 1.5 volts and were calculated using the following electrochemical equivalents:

	<u>g/amp-hr</u>
Ag_2O_2	2.305
Zn	1.220
Reaction (1a) H_2O	0.335
(1b) KOH	1.045
(1c) KOH	2.090

For a number of reasons, the theoretical energy density cannot be realized. Some zinc (5 to 10%) chemically dissolves in the electrolyte and therefore is not used electrochemically. Internal resistance in the cell and the need for some excess electrolyte are among other factors lowering the energy density realized.

B. TAPE FABRICATION

1. Anode

As mentioned previously, the anode consisted of a zinc block over which the activated tapes are drawn.

2. Base Tape

Non-woven fabrics of Nylon[®], Dynel[®], polypropylene, and Dacron[®] in thicknesses from 0.8 to 12 mils have been used for a tape base. The physical characteristics of these materials are given in

Table 1. These materials wet out rapidly with the concentrated KOH electrolyte and retain wet strength and flexibility. Porosity must be such as to limit penetration of Ag_2O_2 but allow electrolytic conduction. Some Ag_2O_2 penetration, primarily during coating, was evident. This did not occur with porous polyethylene and an ion exchange membrane material, but these latter materials tended to limit discharge rates more than the non-woven materials.

3. Cathode

In early experiments, a single tape coated with Ag_2O_2 was wet with electrolyte just prior to discharge. A dual-tape was then tried in which one tape was coated with Ag_2O_2 and a second tape (uncoated) was prewet with electrolyte. This latter configuration eliminates the need for an electrolyte pump and allows more latitude in applying Ag_2O_2 (e.g., impregnation). The dual-tape system has been used in most of this work.

Several methods of applying Ag_2O_2 to the tape base material were used. Impregnation and pressing were tried with some base materials. More often, the Ag_2O_2 was dispersed in an aqueous solution of binder, usually polyvinyl alcohol, and drawn over the prewet tape with a Gardner knife.

Initial attempts to coat the dry fabric were satisfactory with small strips, but prewetting of the fabric was found to be necessary in coating larger pieces of material. The fabric to be coated was saturated with distilled water on a glass plate. Excess water was then drawn off with the Gardner knife. Using this technique the fabric remained dimensionally stable during coating and the tendency for Ag_2O_2 to penetrate into the fabric was reduced.

A typical coating solution had the following composition:

	<u>Parts by Weight</u>
Ag_2O_2^*	30.9
Gelvaton 20-30	5.6
Water (distilled)	63.7

* Ag_2O_2 , as used, analyzed 96% divalent silver oxide, which gives a coating composition of 85 wt-% Ag_2O_2 on a dry basis.

Satisfactory coatings were obtained with Ag_2O_2 content of 85 to as high as 92 wt-%, depending on the nature of the surface being coated and the coating thickness desired.

Table 1
PHYSICAL DATA ON MATERIALS

TAPE BASE MATERIALS

Number	Type	Thickness mils	Weight g/in. ²	Electrolyte Retention 30% KOH g/in. ²	Manufacturer	Miscellaneous
N561	Non-woven nylon	3-4	0.034	0.135	Pellon Corp.	
2505K	Non-woven nylon	5-6	0.038	0.115	Pellon Corp.	
2505	Non-woven nylon	8-10	0.038	0.33	Pellon Corp.	
2505B	Non-woven nylon	10-12	0.038	0.35	Pellon Corp.	
N524	Non-woven nylon	60	0.032	0.80	Pellon Corp.	
EM403	Non-woven Dynel	0.8	0.012	0.012	Kendall Co.	
EM436	Non-woven Dynel	5-9	0.027	-	Kendall Co.	
EM476	Non-woven Polypropylene	2.7	0.023	-	Kendall Co.	
ML410	Non-woven Dynel	3.7	0.029	0.06	Millipore Filter	1.5 micron holes
OH 1.5	Porous Polyethylene	6-7	0.027	-	Millipore Filter	10 micron holes
OS10	Porous Polyethylene	9-10	0.034	-	Gelman Instrument	Nylon reinforced weak acid type, 5 micron holes (dry)
GWA	Ion exchange membrane	5	0.038	-	Gelman Instrument	Nylon reinforced polyvinyl alcohol, 5 micron holes (dry)
GPVA	Ion exchange membrane	5	0.038	-	Gelman Instrument	Nylon reinforced polyvinyl alcohol, 5 micron holes (dry)

BINDERS

Name	Material	Manufacturer	Remarks
Galvatol 20-30	Polyvinyl alcohol	Shawinigan Resins	
Methocel R 65HG	Hydroxypropylmethyl cellulose	Dow Chemical	Slow to wet with strong KOH
PVP K-30	Polyvinyl pyrrolidone	Antara Chemicals	Very slow to wet with strong KOH
CMC 7HCP	Cellulose gum	Hercules Powder	Slow to wet with strong KOH
Acrysol	Polyacrylic acid	Rohm and Haas	Produced brittle coatings, slow to wet

ELECTROLYTES

KOH	30% aqueous
KOH	37% aqueous

CATHODE MATERIAL

Divalent silver oxide	
Ag ₂ O content: 96 wt-%	
Silver content: 93 wt-%	

CATHODE COLLECTOR

Silver metal	
Silver screen	

ANODE MATERIAL-ANODE COLLECTOR

Zinc metal	
Zinc screen	
Zinc dust	

Ames Chemical 325 mesh (<44 micron)

Handy and Harmon Fine silver

New Jersey Zinc Hi-grade

Physical data on the coated tape are listed in Table 2. Impregnation of Ag_2O_2 (T-11 and T-12) was carried out by drawing the fabric through the aqueous Ag_2O_2 slurry. The pressed tapes (T-19, 20, 21, 26) were made by spreading the desired amount of dry Ag_2O_2 mix over a 5 in. x 5 in. fabric area and pressing between flat plates in a hydraulic press at about 30 psi of fabric surface.

Analysis for divalent silver oxide was carried out on the dried coating solutions and on the coated dry tapes. While these analyses agreed within a few per cent, the Ag_2O_2 content found was usually lower than that expected from the initial make-up. This was believed due to reduction of Ag_2O_2 during the mixing, coating, and drying operations. This was confirmed by silver analysis on the same material. The silver analysis agreed with the initial make-up.

4. Tape Stability

Coated dry tapes have been stored in closed containers that prevent exposure to light. No obvious deterioration has been noted under these conditions over periods of three to four weeks. Rolled tapes similar to those to be used in the demonstration units are currently in storage at 90% relative humidity and 100°F. These tapes will be examined periodically to check retention of coating integrity and Ag_2O_2 content.

C. METHOD OF ACTIVATION

To activate the dry tape, the aqueous electrolyte must be introduced just before the tape enters the anode and cathode current collectors. Micro- or macro-encapsulation offers an attractive solution to this problem but will not be used in the feasibility demonstration owing to time limitations. Instead, an uncoated tape prewet with electrolyte will be used in addition to the coated tape. The prewet tape will be stored in a container with a "pop-out" seal. Activation will be accomplished by bringing the two tapes together just ahead of the current collectors. Present operation in the dynamic tape test equipment indicates that the tapes using polyvinyl alcohol as a binder can be activated as close to the current collectors as desired.

Other methods of activation have been considered. A single dry tape has been activated by drawing it over a wicking pad supplied with electrolyte by a metering pump. A porous current collector could be used with electrolyte supplied through the collector. Incorporation of dry powdered KOH into the coated tape has also been tried; water is supplied to activate the tape. It appears that considerably longer activation times are necessary to allow dissolution of KOH and diffusion to form electrolyte. It was hoped that this could be done at the current collectors to take advantage of the heat effect to improve output, but the increased activation time seems to obviate this possibility.

Table 2

PHYSICAL DATA FOR COATED TAPES

COATED ON PELLON (NON-WOVEN NYLON)

Tape	Base Material	Binder	Dry Thickness (mil)	Coating (wt-%) Composition Make-up	Analysis	Total Wt. Ag ₂ O ₂ g/in. ²	Dry Tape Ag ₂ O ₂ Wt. g/in. ²	Comments
T-1	2505K	Gelvatol 20-30	16-25	-	74	-	-	Very rough surface
T-11	"	"	21-26	95	-	0.23	0.14	Impregnated rough and dusty surface
T-20	"	None	-	100	-	-	-	Pressed Ag ₂ O ₂ into tape
T-2	N521	Gelvatol 20-30	6-9	80	72	0.21	0.12	Fairly smooth
T-5	"	"	6-8	80	66	0.092	0.028	Fairly smooth
T-7	"	"	6-7	80	78	0.078	0.017	2 wt-% Conductex SC carbon black added; rough surface
T-8	"	"	9-11	80	-	-	-	2 wt-% Conductex SC carbon black added; rough surface
T-10	"	"	7-8	85	-	-	-	Fairly smooth
T-13	"	"	9-12	75	-	0.077	0.026	Fairly smooth
T-15	"	"	6-10	85	-	-	-	5 wt-% carbon black used (Aquablak 36)
T-17	"	"	8-10	90	79	0.17	0.11	Fairly smooth
T-18	"	"	8-10	94	88	0.10	0.054	Fairly smooth
T-22	"	Methocel	3-7	90	79	0.12	0.066	Fairly smooth
T-27	"	Gelvatol 20-30	10-11	92	81	0.16	0.10	Fairly smooth
T-29	"	Gelvatol 20-30	11-12	92	76	0.18	0.11	Coating tends to crack
T-32	"	"	11-14	92	69	0.21	0.12	Coating cracks
T-33	"	"	10-12	92	-	-	-	Pressed dry KOH-Ag ₂ O ₂ mix into tape
T-26	2505	None (KOH)	-	-	-	0.085	0.047	Pressed dry methocel-Ag ₂ O ₂ mix into tape
T-19	2505	Methocel	-	-	-	-	-	Impregnated, rough and dusty surface
T-12	N524	Gelvatol 20-30	-	95	-	-	-	

COATED ON OTHER BASE MATERIALS

T-3	OH 1.5	Gelvatol 20-30	11-12	-	22	0.11	0.018	Very smooth
T-4	GWA	Gelvatol 20-30	7-10	80	-	-	-	Smooth
T-6	EM403	"	3-4	80	50	0.051	0.018	Smooth
T-9	OS-10	S55L	-	-	-	-	-	Smooth
T-14	ML410	Gelvatol 20-30	11-15	85	87	0.10	0.062	5 wt-% Carbon black used (Aquablak 36)
T-16	ML410	"	7-10	90	81	0.13	0.081	Fairly smooth
T-23	ML410	Methocel	5-6	94	89	0.074	0.042	Smooth
T-24	EM476	Methocel	5-6	94	89	0.061	0.034	Smooth
T-25	EM436	"	9-12	94	89	0.13	0.086	Rough, fibrous, tends to impregnate
T-28	EM476	"	10-11	90	80	0.104	0.066	Flakes off, smooth
T-30	EM403	"	7-8	92	53	0.084	0.032	Flakes off, smooth
T-31	EM476	Gelvatol 20-30 + Methocel	8-10	~85	51	0.104	0.041	Flakes off, smooth

D. TAPE TEST PROCEDURE AND RESULTS

The main variables measured in the dynamic test device are summarized below:

<u>Variable</u>	<u>Typical Values/Range</u>
Current Density (discharge rate)	0.15-1.7 amps/in. ² (1 to 10-ohm loads)
Electrolyte Feed Rate	0.15-2 cc/min.
Tape Speed	0.2-10 inches/min.
Tape Pulling Force	0.5-2 pounds
Electrode Contact Pressure	1-9 ounces (0.08-0.75 lb/in. ²)

The test equipment has been described in Section IIA. A number of tape base materials and coating binders were subjected to preliminary screening using a simple static test requiring only a square inch of tape. The more promising combinations were tested further in dynamic operation. The results are given in Table 3. The preliminary dynamic tests are given in the Appendix.

The tests to date have been carried out primarily to determine the general characteristics of a tape system and to obtain an operable tape for use in the feasibility demonstration. Since recurrent modifications on the test equipment and coating methods were made, direct comparison of test results is not possible. For example, the current collectors have been decreased in width to 7/8 in. and redesigned to reduce alignment problems in the "dual-tape" system. Since the effect of collector shape (width-to-length ratio) and area has not been investigated, it is not known whether comparisons based only on current density are valid.

The test procedure consisted of initial determination of the open circuit voltage followed by discharge at increasing rates to determine the maximum rate obtainable at a fixed tape speed. A tape speed of 1 inch per minute was used in most of the tests. If a steady discharge was maintained for a two-minute period, the discharge rate was increased further (usually doubled) by decreasing the load resistance. While a two-minute discharge probably did not bring the tape to steady-state conditions, it did provide a complete change of depolarizer at the collectors.

Table 3
LABORATORY TAPE TEST RESULTS

Run No.	Separator	Voltage, Volts	Load Resistance ohms	Current Density ^a amps/in. ²	Tape Speed, in./min	Time Maintained, min	Open Circuit Voltage	Remarks
T-5-44906	2505B	1.26	5	0.339	1	0.3	1.51	With Ag and Zn screens, "Dual Tape"
T-6-27750	2505B	1.40	10	0.15	1	3		With and without Ag screen, "Dual Tape"
	2505B	1.30	3	0.45	1	2		
T-6-44901	2505B	1.30	10	0.138	1	0.25	1.52	Ag and Zn screens, "Dual Tape"
	2505B	1.10	2	0.55	1	3		Ag and Zn screens, "Dual Tape"
	2505B	1.40 ^c	10	0.14 ^c	~0.3	1		Ag and Zn screens, "Dual Tape"
T-8-44902	2505B	1.20 ^c	10	0.10 ^c	1	2	1.52	Ag and Zn screens, "Dual Tape"
T-9-44901	2505B	0.8 ^c	10	0.08 ^c	1	2	1.56	Ag and Zn screens, "Dual Tape"
T-10-27750	2505B	1.34	10	0.145	1	2	1.56-1.58	Ag and Zn screens, Tape very slow to wet
	2505B	1.0 ^c	2	0.5 ^c	0.5	2		"Dual Tape"
T-11-44904	2505B	1.43	10	0.189	1	2	1.52	"Dual Tape", same with Ag and Zn screen
	2505B	1.30	2	0.84	1	3		"Dual Tape"
T-12-44901	2505B	1.45	10	0.145	1	0.2		"Dual Tape" + additional KOH
	2505B	1.42	4	0.362	1	0.5		"Dual Tape" + additional KOH
	2505B	1.39	2	0.70	1-0.5	0.75		"Dual Tape" + additional KOH
	2505B	1.20	1	1.29	1	2		"Dual Tape" + additional KOH, output drops off
T-13-44902	2505B	1.43	10	0.19	1	4	1.55-1.59	Electrolyte Feed ~0.3 cc/min.
	2505B	1.20 ^c	2	0.86 ^c	1	3		Ag and Zn Blocks appear clean after run
T-14-44906	2505B	1.26	10	0.17	1	0.5	1.52-1.56	"Dual Tape", voltage fluctuates
T-15-44906	2505B	1.26	10	0.17	1	0.5	1.52	"Dual Tape", voltage fluctuates
T-16-44906	2505B	1.40	10	0.183	1	1	1.52	"Dual Tape", Ag screen
T-16-44904	M1410	1.40	10	0.185	1	2		"Dual Tape"
T-16-44904	2505B	1.0 ^c	2	0.65 ^c	1	2		"Dual Tape"
T-16-44906	2505B	1.06	2	0.695	1	0.5		Ag screen
	2505B	1.36	2	0.90	1	1		"Dual Tape", Ag screen, pressed prior to discharge
T-19-44907	2505B	1.38	2	0.912	0.5 to 3	0.5	1.60	"Dual Tape", Ag screen
	2505B	1.20	1	1.56	1	0.1		"Dual Tape", Ag screen
T-20-44907	2505B	1.34	2	0.873	1	2	1.59	"Dual Tape", Ag screen
T-22-44907	2505B	1.42	10	0.189	0.5	2	1.63	"Dual Tape", Ag screen, slow to wet
	2505B	1.36	4	0.456	1	0.5		"Dual Tape", Ag screen, slow to wet
	2505B	1.22	2	0.808	0.5	2	1.60	"Dual Tape", Ag screen, slow to wet
T-23-44908	2505B	1.42	10	0.195	1	0.5	1.61	"Dual Tape", no screen-additional pressure required
	2505B	1.42	16	0.323	1	0.3		"Dual Tape"
	2505B	1.10 ^c	1	1.40 ^c	1	0.5		"Dual Tape"
T-24-44908	2505B	1.47	10	0.20	1	1	1.6-1.63	"Dual Tape"
	2505B	1.30 ^c	2	0.66 ^c	1	3		"Dual Tape"
T-25-44908	2505B	1.38	10	0.192	0.5-1	3	1.62	Tape somewhat rough, slow to wet
	2505B	1.12	2	0.73	1	2.5		"Dual Tape", distilled water wet separator
T-26-44908	2505B	0.70	10	0.098	1	0.4	1.10	Added electrolyte at current collector
	2505B	1.47	10	0.204	1-0.5	0.5	1.61	Added electrolyte at current collector
	2505B	1.40	4	0.475	0.5	1		Added electrolyte at current collector
	2505B	1.38	2	0.92	1	0.5		Added electrolyte at current collector
	2505B	1.28 ^c	1	1.70 ^c	1	1.5	1.59	"Dual Tape"
T-27-44909	2505B	1.34	2	0.88	1	2		"Dual Tape", electrolyte feed, ~0.35 cc/min.
	2505B	1.26 ^c	1	1.6 ^c	1			

^a Based on area of smaller collector

^c Average value

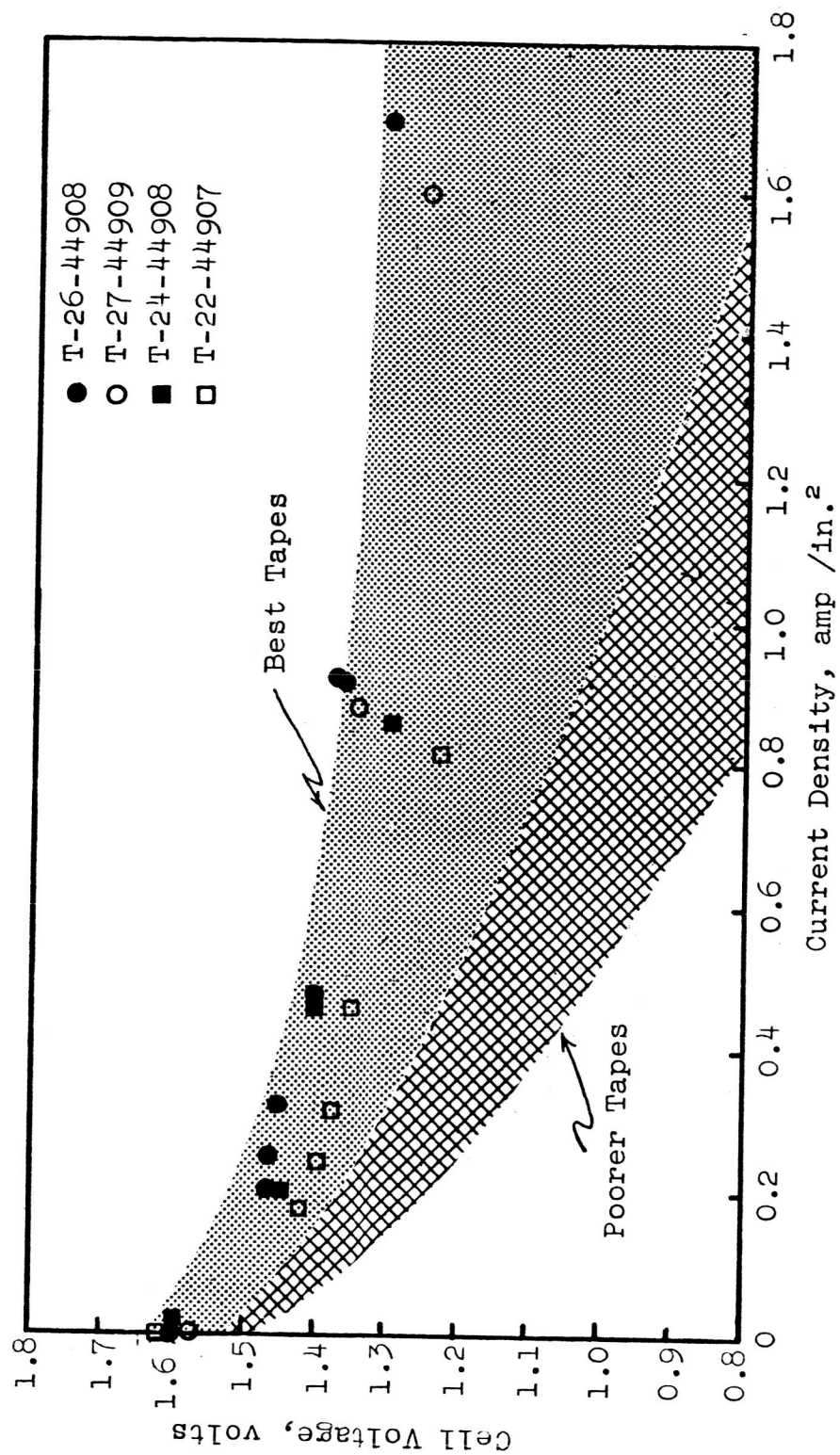
While no detailed experiments have been conducted to provide mathematical relations for the variables involved, a number of general observations have been made. Assuming a fixed tape speed with excess electrolyte supplied, the maximum discharge rate maintainable depends primarily on the percentage of Ag_2O_2 in the coating and the type of material used for the separator and coating support. Complete loss of output was most often due to penetration and deposition of silver on the zinc collector. As the percentage of Ag_2O_2 in the coating decreased with the same type of tape, lower output voltages were obtained.

Coating uniformity and smoothness must be such that the collector contacts essentially all the coated area beneath it. With a screen or roller collector, more roughness could be tolerated. Increasing pressure on the current collectors increased output only momentarily when good contact was already being made. A force of 2 to 5 ounces was generally sufficient for good contact with smooth tape. When there was excess Ag_2O_2 on the tape for the conditions used, slowing or stopping the tape usually produced a small rise in output, at least temporarily. This is believed due to better contact with and improved conductivity of the discharging coating.

The use of very thin (1-3 mil) permeable non-woven materials allows high discharge rates to be attained, but failure due to zinc fouling is rapid. Materials of low permeability eliminate the fouling but also limit discharge severely. The best compromise solution found to date is the use of a thick (10 mil), highly permeable separator/electrolyte feed tape with a thin (1-3 mil) coated tape. The use of hydroxymethylcellulose as a binder seems to limit migration of silver and degradation of Ag_2O_2 during coating. However, the resulting coating is slow to wet with electrolyte, requiring a longer contact length with electrolyte tape or a slower tape speed.

Typical voltage-current density characteristics of the tapes tested are represented by the shaded area in Figure 12. The actual data on three of the better coated tapes fabricated to date are also shown in this figure with the test results on a tape without binder for comparison. This latter pressed tape shows lower voltage loss, especially at the higher current densities but tended to shed Ag_2O_2 on handling.

The range of output power and energy density for some of the tapes is summarized in Table 4. The current efficiencies were calculated from the make-up composition of the coating. Several of the values would be higher if the Ag_2O_2 content determined by coating analysis were used assuming the remainder to be Ag_2O . The actual system energy density listed was calculated using the theoretically consumed weight of zinc and includes the weight of separator, coated tape, and electrolyte actually used excluding hardware.



Conditions: Tape Speed 1 in./min, 37% KOH Electrolyte, Ag₂O₂/Zn Couple

Figure 12. Dry Tape Tests on Laboratory Tester, Range of Test Results and Actual Results on Four Tapes.

Table 4
SUMMARY OF OUTPUTS AND ENERGY DENSITIES OBTAINED ON LABORATORY DRY TAPE TESTER
SYSTEM: Ag_2O_2 / KOH/Zn

Run No.	Tape Speed in./min	Current Density amp/ft ²	Current Efficiency %	Power Output, watts	Energy Density, watt-hr per pound of			System ^a Actual
					Dry Tape	Electrolyte	Theor. Zn + KOH ^b	
T-2-27747	0.2	20	36	0.20	67			
T-2-27747	1	50	30	1.0	61	22		
T-3-27746	1	50	69	0.95	65			
T-6-44901	1	90	82	0.65	54	11		
T-13-44902	1	123	76	0.85	94	21	30	
T-16-44905	1	130	38	0.94	65			
T-22-44907	0.5	116	~100	0.76	137		47	
T-24-44908	0.75	124	~100	0.86	170		40	29
T-27-44909	1	230	78	1.50	108		48	24

^a Includes tape, Ag_2O_2 , electrolyte actually used and 110% of theoretical Zinc.

^b KOH based on equation (1b)

IV. PHASE II. PROOF, DEMONSTRATION AND DELIVERY

1. The feasibility of the dry tape battery concept has been demonstrated on the laboratory tape test device and with the prototype of the final activation unit. Preparation for delivery of the final units is underway.
2. The system has been characterized on the laboratory tape test device for utilization of Ag_2O_2 . Tests on the final units will be made, and optimized prediction of future capabilities of the device can then be given.
3. Preparation of the four activation units and tapes for them is currently underway.

V. FUTURE PLANS

A. MECHANICAL

Construction, assembly, and testing of the final units will be carried out. The "tape deck" subassembly and the engagement of the drive unit with the deck will be separately tested. Operational tests of the completed final units at various loads will also be made.

B. CHEMICAL

Fabrication and characterization of the tapes for incorporation in the demonstration units will be completed. Storage tests on tapes now in storage will be continued to determine stability of tape and stringency of storage requirements.

As time permits, the following factors will be investigated using the laboratory tape test device:

Higher discharge rates

Shape factor of solid electrodes

Porous zinc roller and roller cathode current collector

Single tape with zinc and Ag_2O_2 coatings

Bipolar tape

Other couples

APPENDIX I
PRELIMINARY TAPE TEST RESULTS ON LABORATORY TESTER

Run No.	Separator	Voltage Volts	Load Resistance ohms	Current Density ^a amps/in. ²	amps/ft. ²	Tape Speed in./min	Time Maintained min	Open Circuit Voltage	Remarks
T-1-27746	None	1.51	10	0.075	11	1	1	1.56	Poor contact due to rough tape surface, 2 in. ² zinc
T-1-27748	None	1.39	2	0.355	51	1	2		Gold roller cathode collector
	2505	1.50	10	0.16b	23 ^b	1	0.5		Gold roller cathode collector
	2505	1.40	3	0.49b	70 ^b	1	1		Gold roller cathode collector
	2505	1.40	2	0.72b	104b	1	0.5		Gold roller cathode collector
T-2-27746	None	1.20 ^c	10	0.20 ^c	29 ^c	1	2	1.56	1 in. ² zinc
	2505	1.14	1	1.1	158	10	0.1	1.65	Additional Ag ₂ O ₂ spread
	2505	1.32	4	0.28	40	2	-		Additional Ag ₂ O ₂ spread
	2505	1.24	2	0.57	82	2	-		Additional Ag ₂ O ₂ spread
T-2-27747	None	1.50	5	0.25	36	1	1	1.50	Ag screen cathode collector
	None	1.40	2	0.65	93	1			Ag screen cathode collector
	None	1.30	1	1.23	177	1	0.5	1.55	Ag screen cathode collector
	2505K	1.46	10	0.14	20	0.2	3		Ag screen cathode collector
T-3-27746	2505K	1.20	2	0.56	81	0.5	2	1.58	Ag screen cathode collector
	2505K	1.49	2	0.65b	93b	1			Ag screen cathode collector and Zn strip anode
	2505K	1.24	2	0.62	89	1	2	1.58	Ag screen cathode collector
	None	1.29	1	0.63	91	1	2		Ag screen cathode collector
T-4-27748	2505B	1.49	10	0.16	23	1	0.5	1.66	"Dual Tape" system
T-4-27749	None	1.50	10	0.16	23	1	0.5	1.52	Zn screen anode
T-5-27749	None	1.36	10	0.13	19	1	-	1.54	With and without Ag screen cathode
	N561	1.30	6	0.23	33	1	-	1.54	With and without Ag screen cathode and Zn screen

a Based on area of smaller collector

b Actual current

c Average value

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